An Introduction to Marine Composites

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Presentation Overview

- **Why use composites in the marine environment**
- **What are they**
- **How to analyze them**
- **Design Examples**
  - **IACC rudder**
  - **78’ performance cruiser**
- **A marine composites dissertation project**

Why Marine Composites?

- Approximately 1/3 of marine applications are now made of composites
- Low maintenance requirements (low life-cycle costs)
- High specific material properties
- High geometric flexibility
- Good moisture stability

Why not?

- High Initial Cost
- Tight tolerances required
- Fire/smoke toxicity
- Environmental

A "Composite"

- A combination of more than one material with resulting properties different from the components
- Examples:
  - Reinforced concrete
  - Wood
  - Polymer composites (1000+ resins, 25+ fibers, 20+ cores)
  - Note: a "composite ship" is not a composite material

Material Properties

- Isotropic Materials (ie metals)
- E

∀ ν

∀ σ_t , σ_c , τ

- Transversely Isotropic Materials (ie one fiber in resin)
- E_x (fiber direction), E_y , G_{xy}

∀ ν_{xy}

∀ σ_{xt} , σ_{xc} , σ_{yt} , σ_{yc} , τ_{xy}

Analysis Methods

- **Classical Lamination Theory – Timoshenko's layered stiffness/stress approach. Uses matrix algebra.**
- **"Blended Isotropic" – ABS Method**
- **Empirical - Gerr**

Methods Compared

- CLT
  - Analytically difficult
  - Accurate to within 1% if base properties are known.
  - Possible unconservative inaccuracy to 15%
- “Blended Isotropic”
  - Analytically easy
  - Accuracy to within 1% if all properties are known.
  - Possible unconservative inaccuracy to a factor of 4!

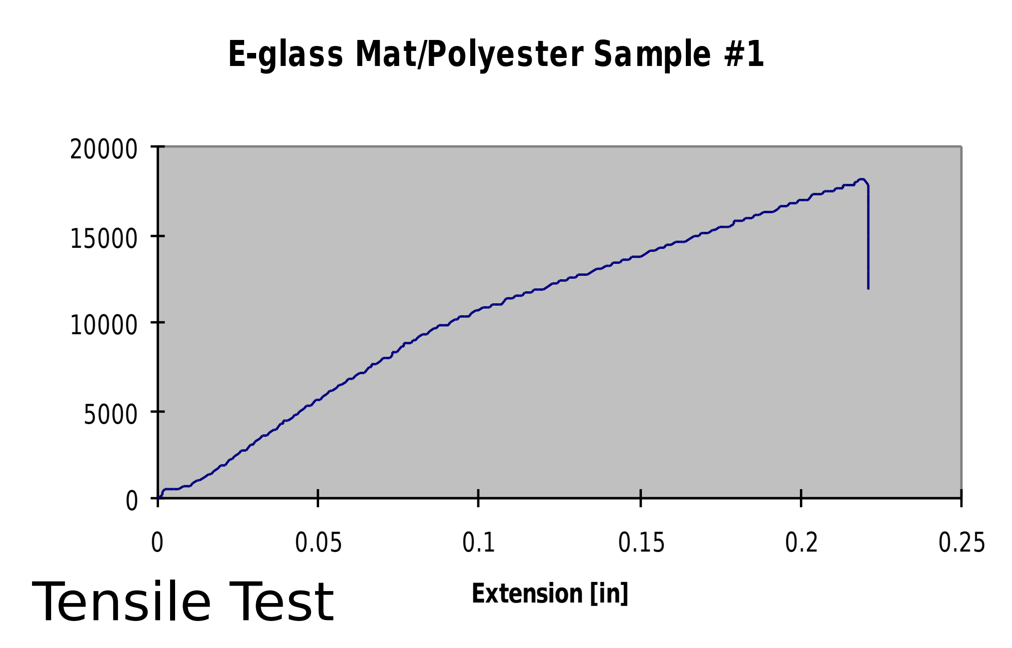
Suggestions

- **Use “blended isotropic” for preliminary design (or to check for ABS compliance) only!**

- **<u>Use CLT for all final design!</u>**

Typical Material Properties

- **Mostly linear stress/strain**
- **Brittle (0.8-2.7% ultimate strain) resins or fibers**
- **Stiffness and St… tests – Wet/Dry)**
  - **Tensile**
  - **Compressive**
  - **Shear**
  - **Flex**
  - **Fatigue**



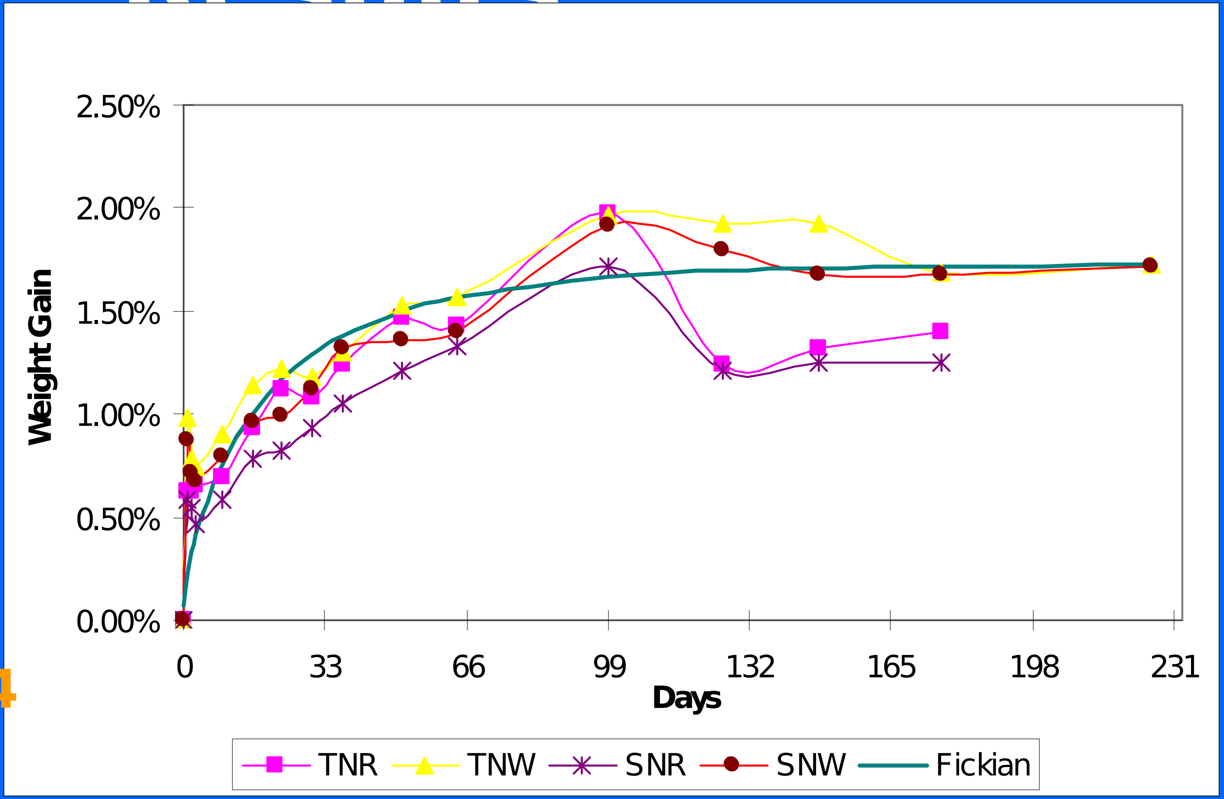
Tensile Test

Moisture Absorption Results

1.8% weight gain for submerged

1.3% for 100% relative humidity

Equilibrium in 4 months



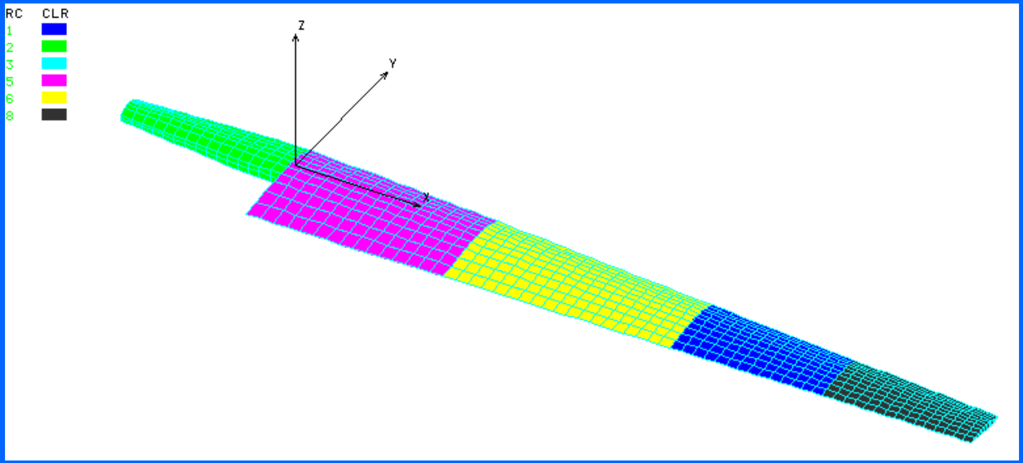
Example Design Problem – IACC Rudder

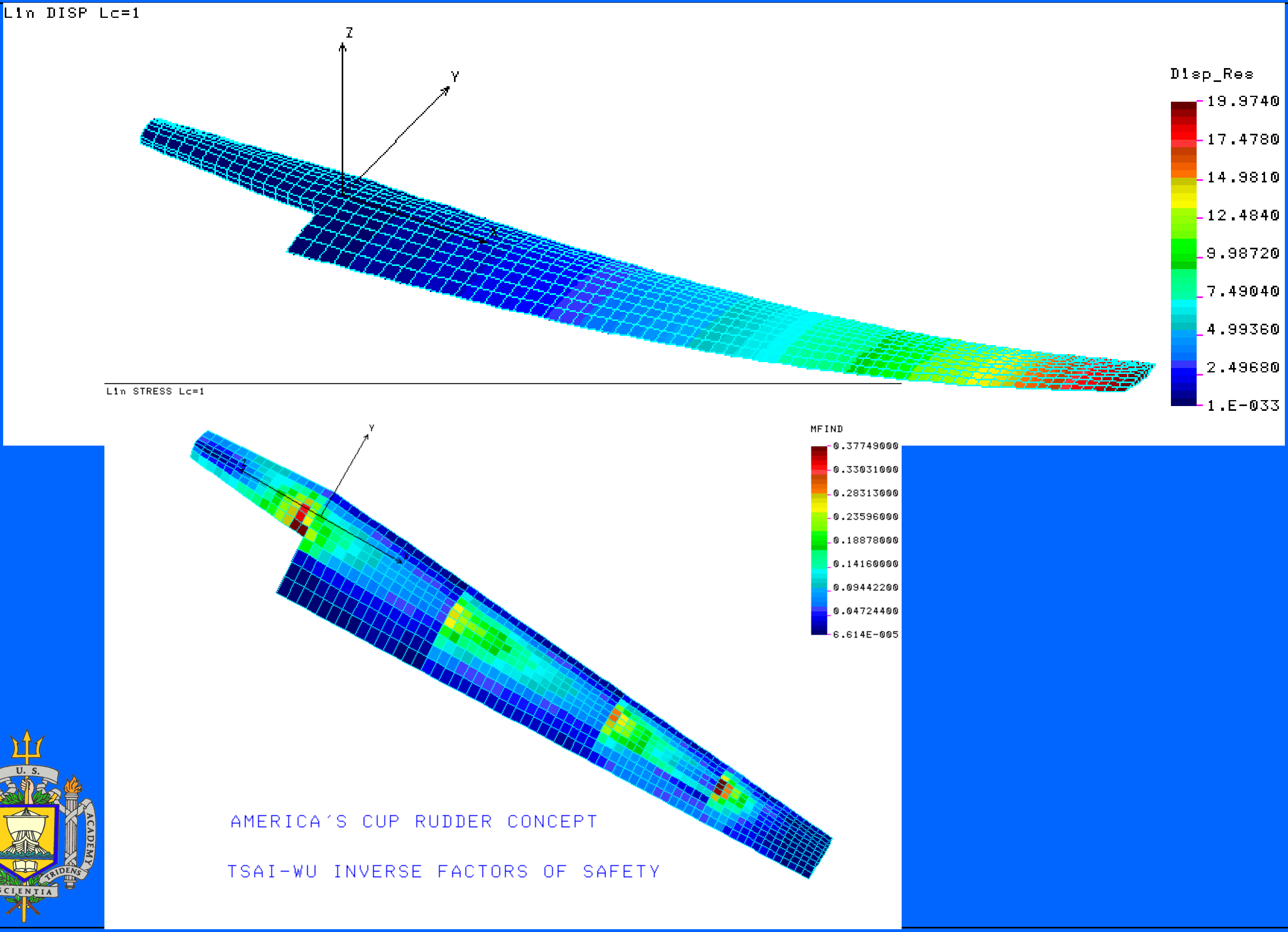
- Goal: As light as possible without breaking!
- Construction: Carbon fiber and epoxy
- Loads from Lift equations and CFD

Approach

- **Geometry**
- **Loads**
  - **Fwd speed**
  - **Backing speed**
  - **Angle of Attacks**
- **Preliminary analysis from beam equations/CLT / lift equation**

- **FEA model**
  - **Laminate tailoring**
  - **CFD loads**
  - **Tsai-Wu and Hashin failure criteria**

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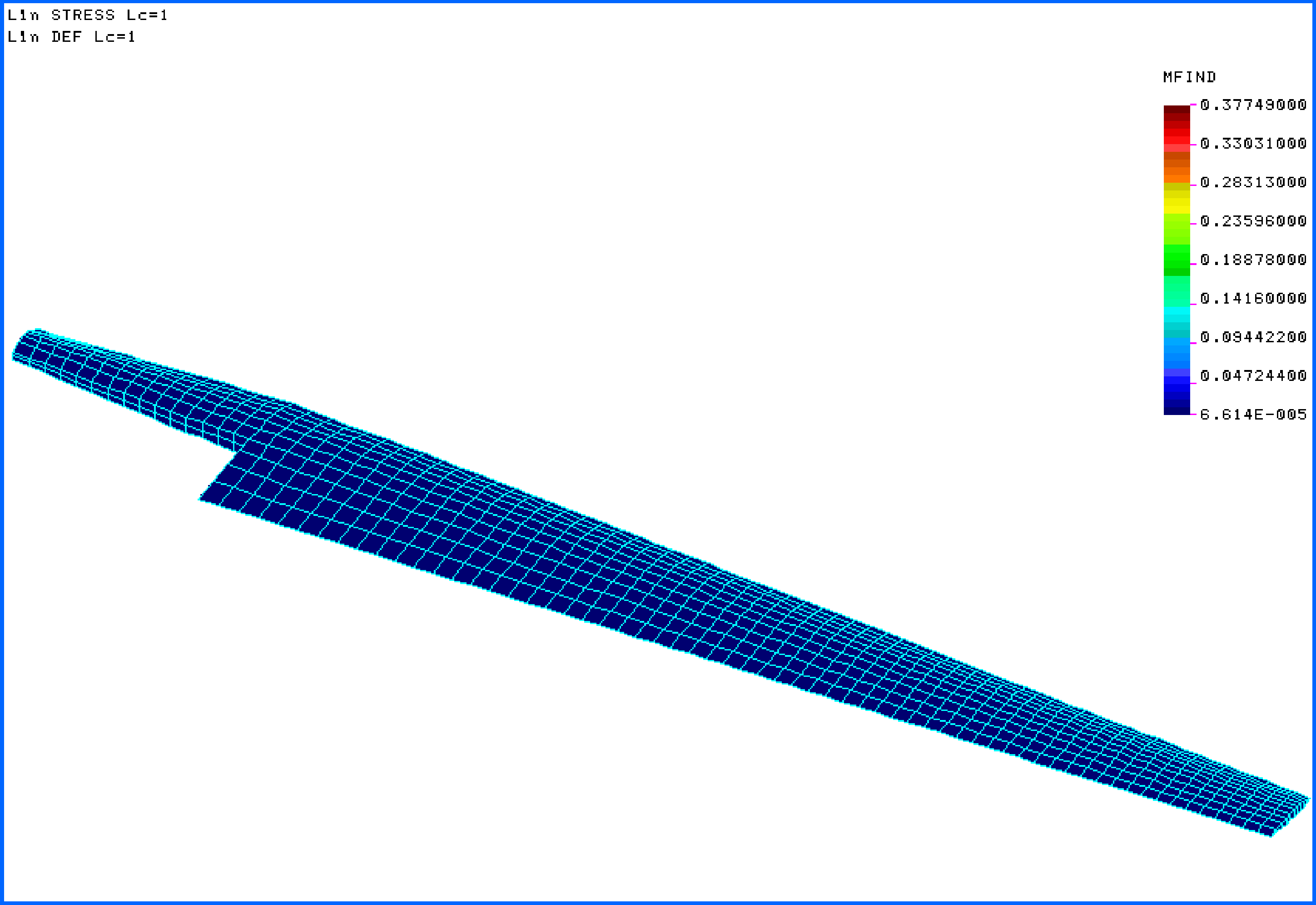
AMERICA'S CUP RUDDER CONCEPT
TSAI-WU INVERSE FACTORS OF SAFETY



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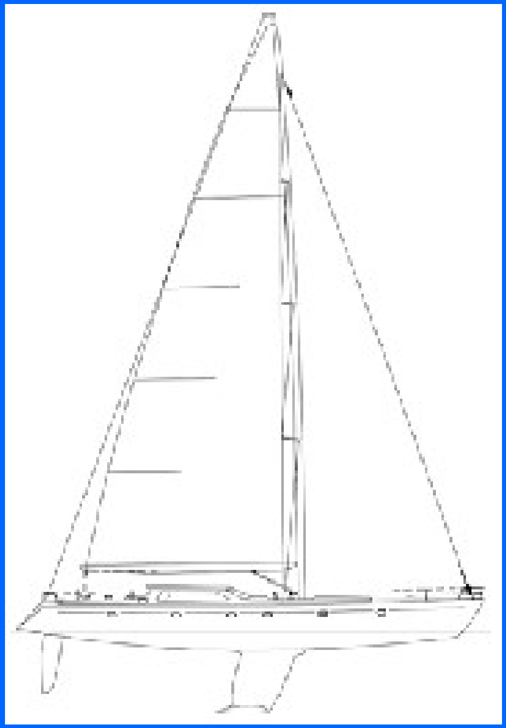
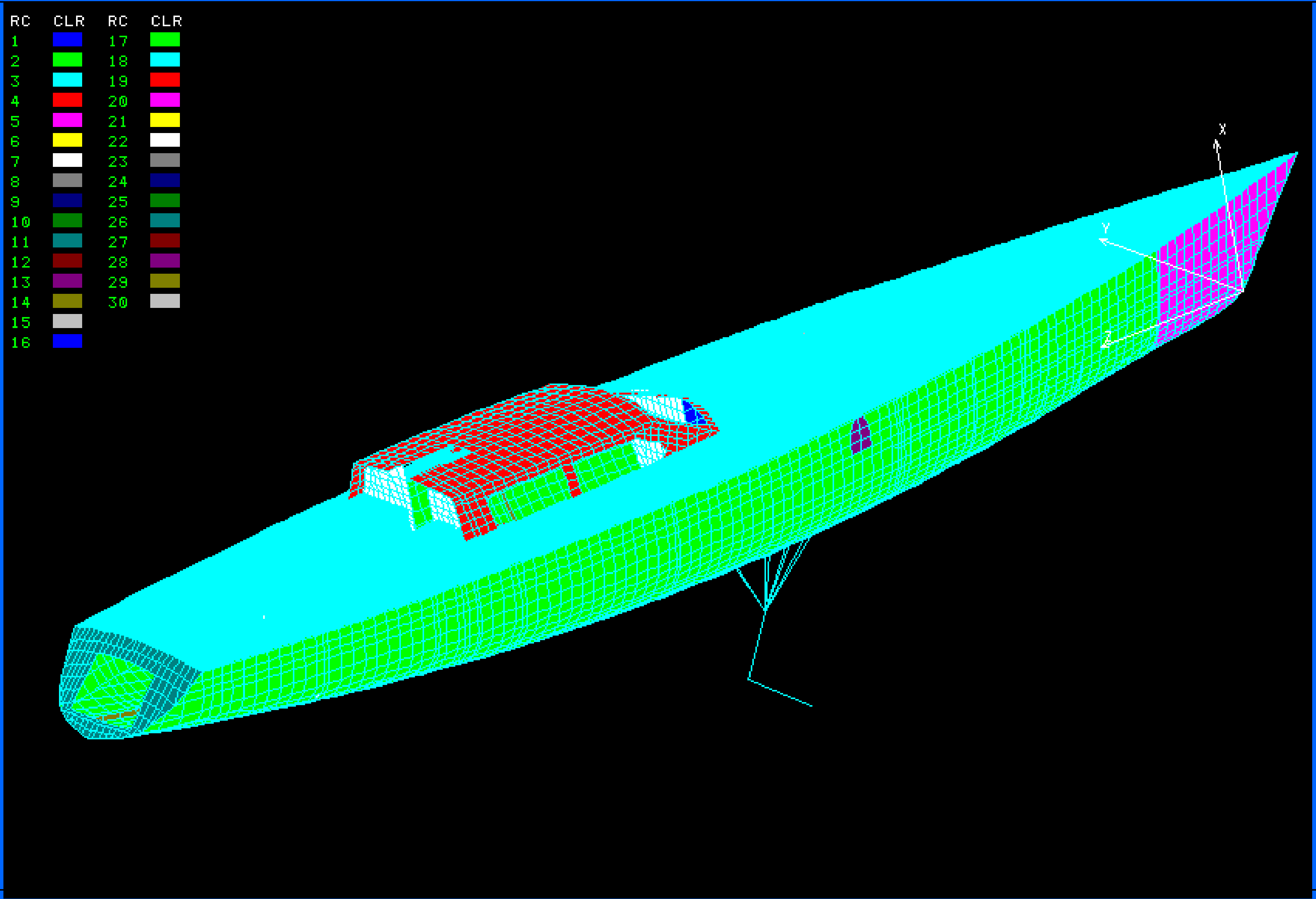
77 foot Performance Cruiser



- Carl Schumacher design
- Building at Timeless Marine, Seattle
- To ABS Offshore Yacht Guide

Approach

- Preliminary design using CLT ("Laminator"), MathCad (for ABS equivalent) and Excel (ABS Guide)
- Final design using FEA
- Nine load cases
  - 15% increased in FEA over ABS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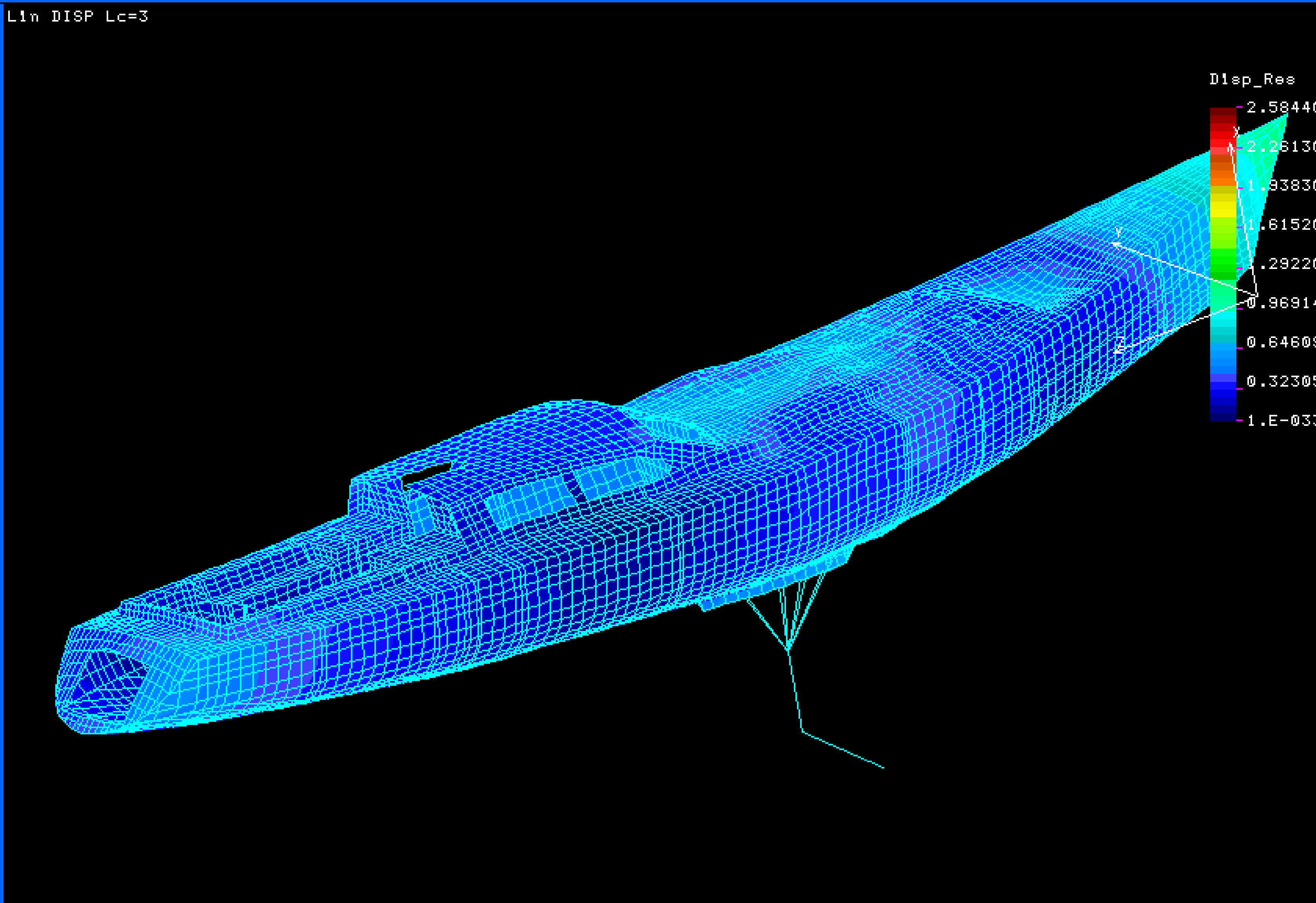
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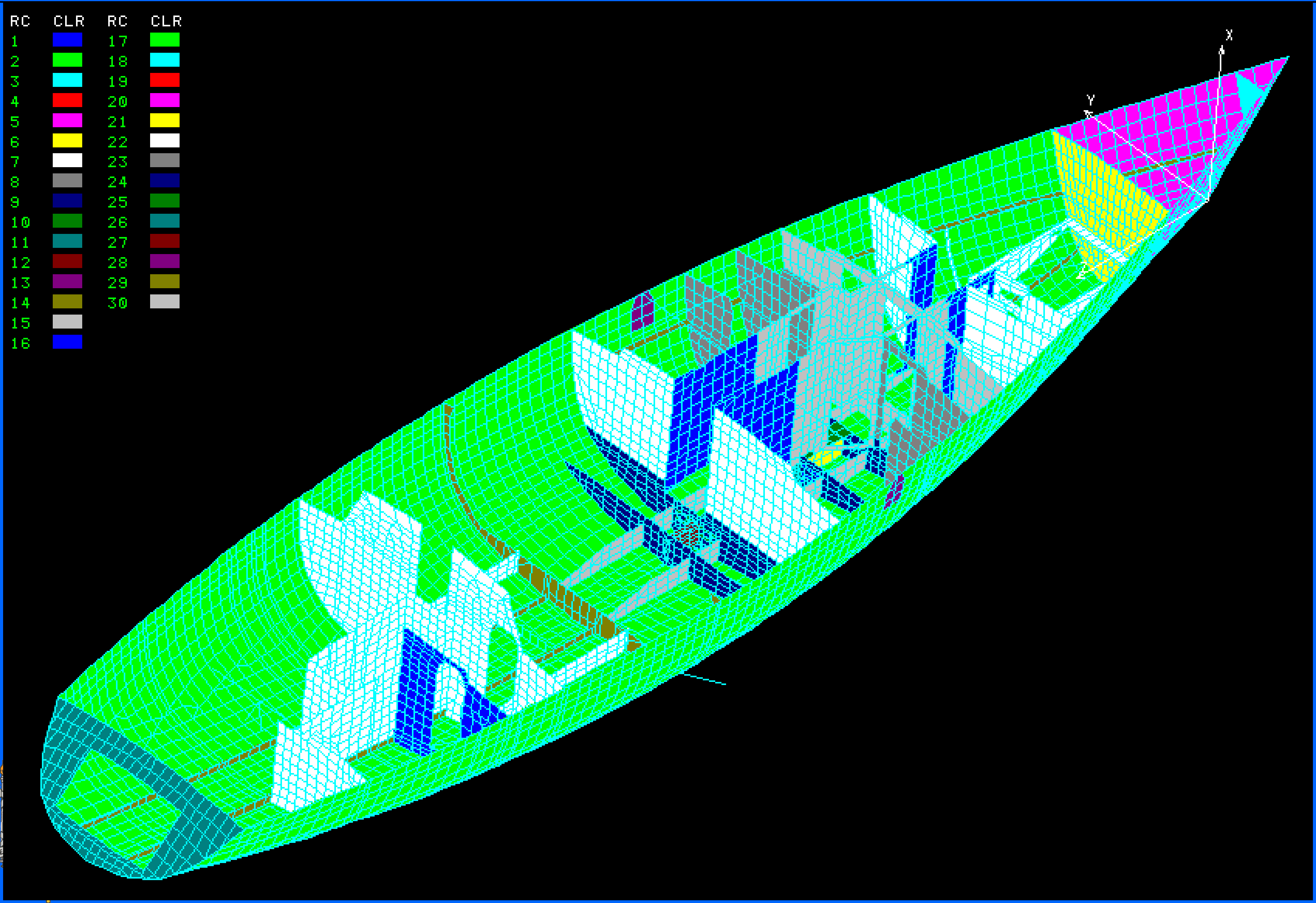
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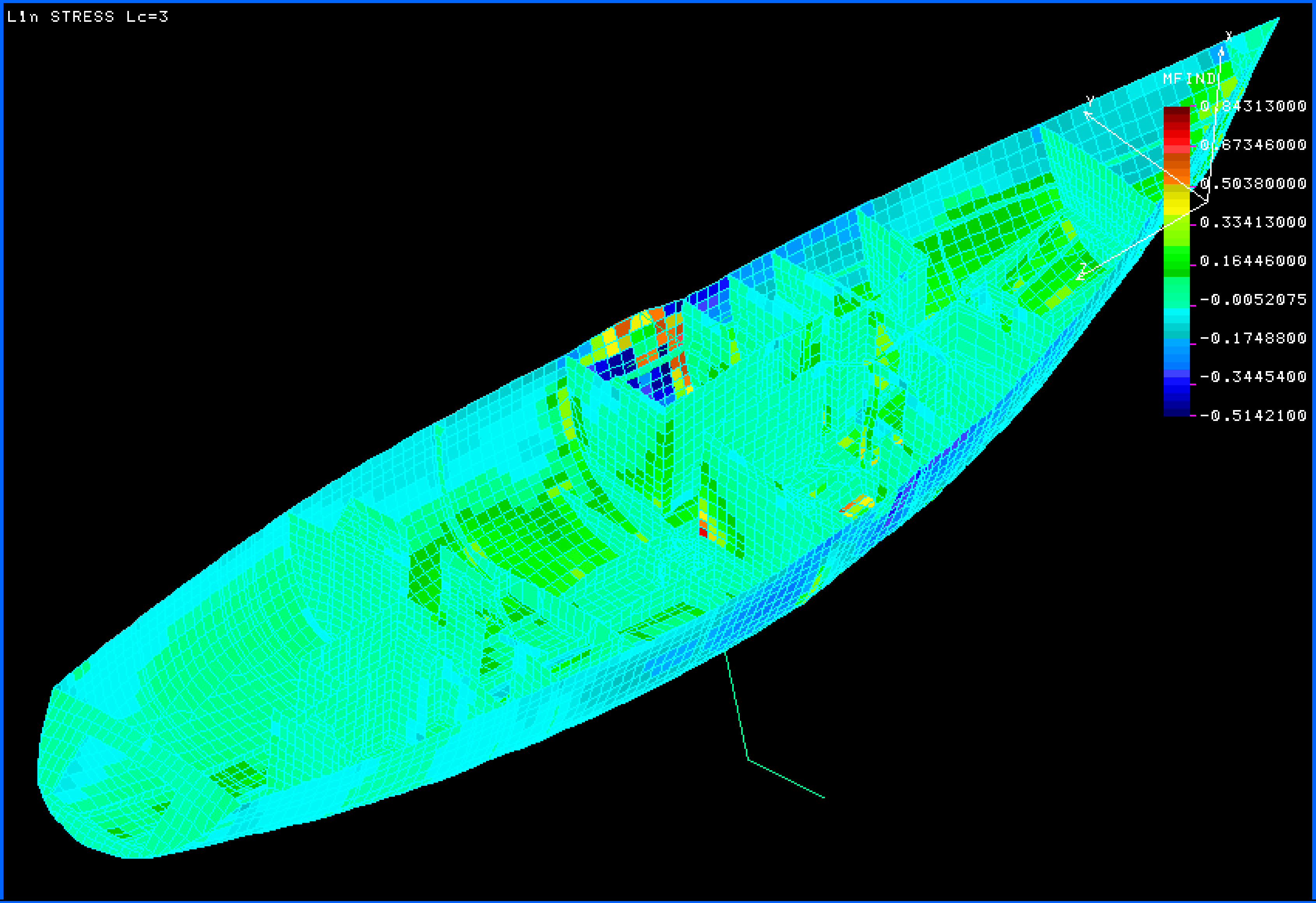
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My Dissertation

- **Extend the standard fatigue methods used for metal vessels to composite vessels**
- **Verify the new method by testing coupons, panels and full-size vessels.**

Simplified Metal Ship Fatigue Design

1. **Predict wave encounter ship "history"**
2. **Find hull pressures and accelerations using CFD for each condition**
3. **Find hull stresses using FEA**
   - **Wave pressure and surface elevation**
   - **Accelerations**
4. **Use Miner's Rule and S/N data to get fatigue life**

Project Overview

- Material and Application Selection
- Testing (Dry, Wet/Dry, Wet)
  - ASTM Coupons, Panels, Full Size
  - Static and Fatigue
- Analysis
  - Local/Global FEA
  - Statistical and Probabilistic

Material & Application Selection

Ideally they should represent a large fraction of current applications!

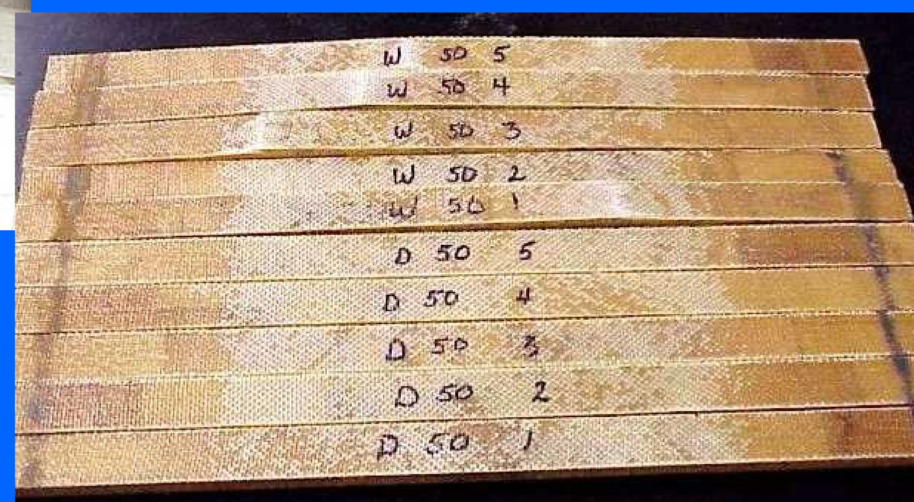
- **Polyester Resin (65%)**
- **E-glass (73%)**
- **Balsa Core (30%)**
- **J/24 Class Sailboat**
  - **5000+ built**
  - **Many available locally**
  - **Builder support**
  - **Small crews**

Another day of research…

Finite Element Analysis

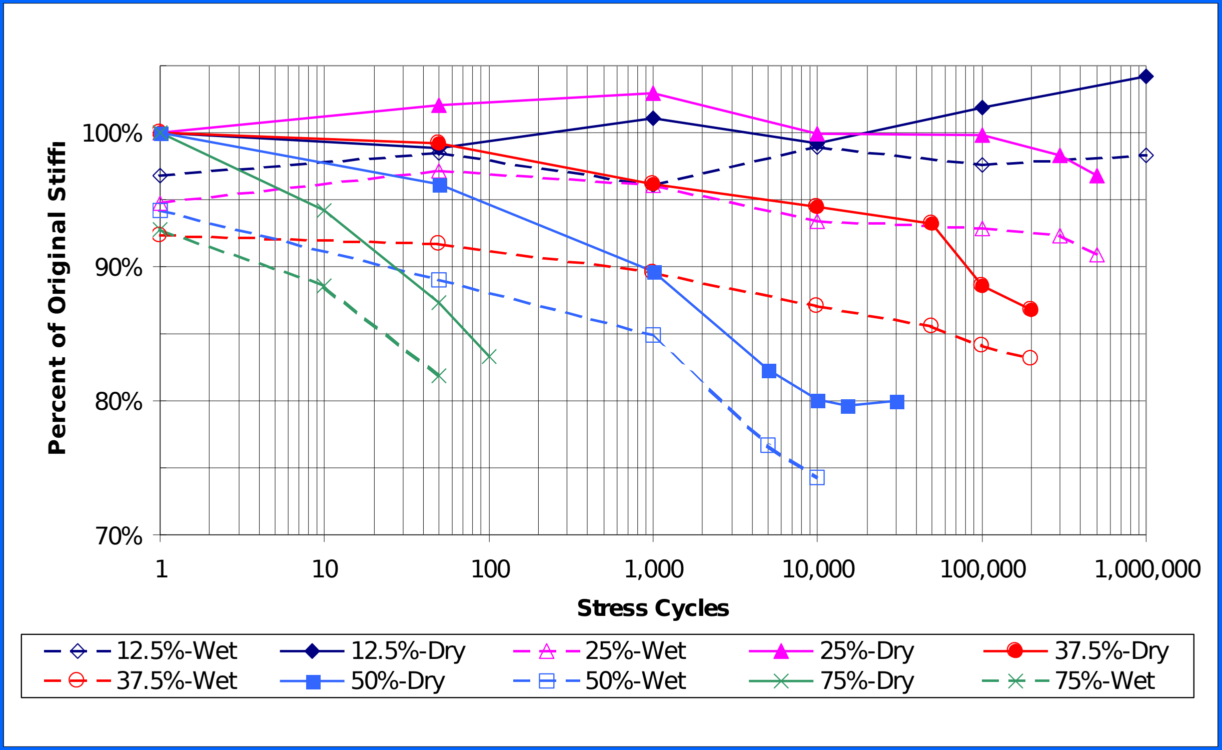
- Coupon, panel, global
- Element selection
  - Linear/nonlinear
  - Static/dynamic/quasi-static
  - CLT shell
  - Various shear deformation theories used (Mindlin and DiScuiva)
- COSMOS/M software
- Material property inputs from coupon tests

Fatigue Testing



Fatigue Results – S/N Data

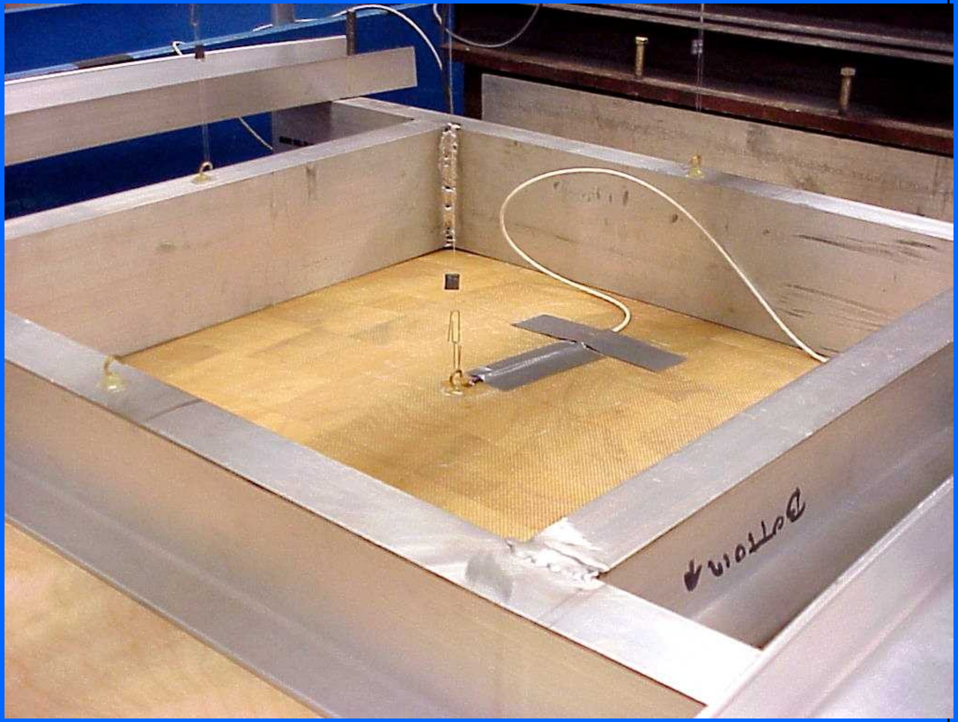
Moisture decreased initial and final stiffness but the rate of loss was the same.



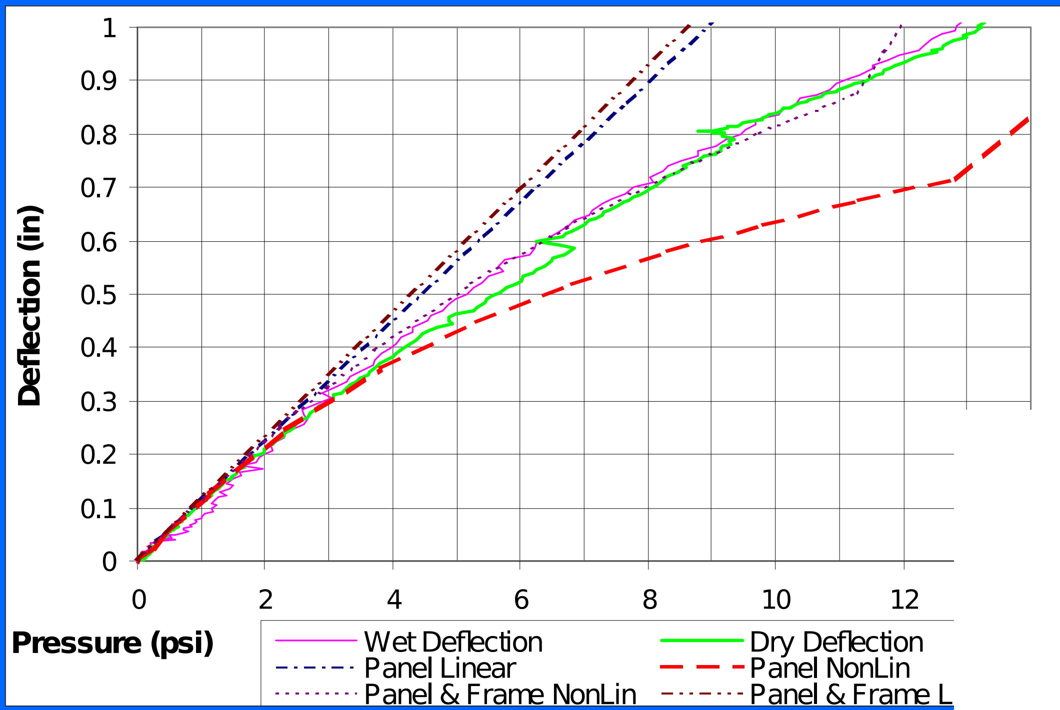
Specimens failed when stiffness dropped 15-25%
No stiffness loss for 12.5% of static failure load specimen
25% load specimens showed gradual stiffness loss

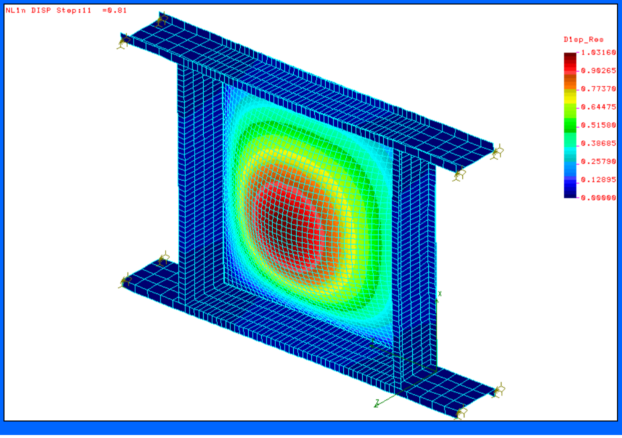
Panel Analysis

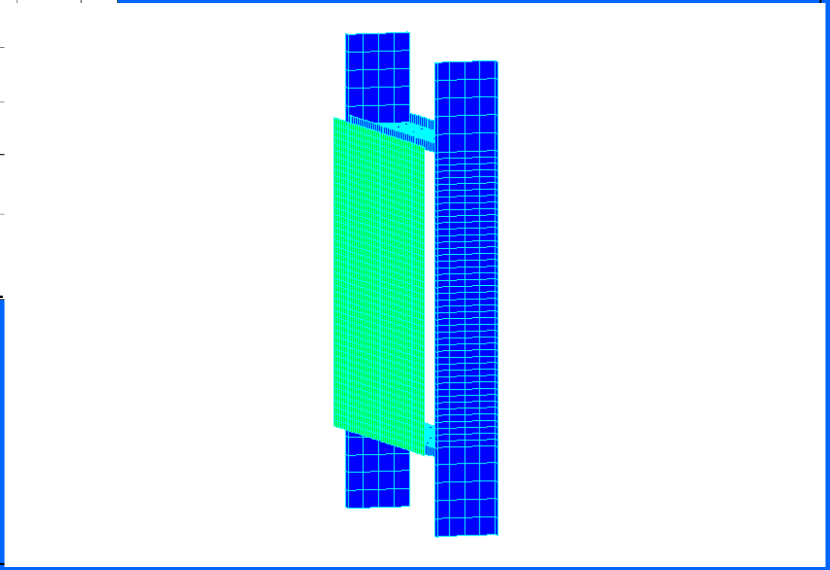
- Responds to USCG/SNAME studies
- Solves edge-effect problems
- Hydromat test system
- More expensive
- Correlated with FEA



Panel FEA Results

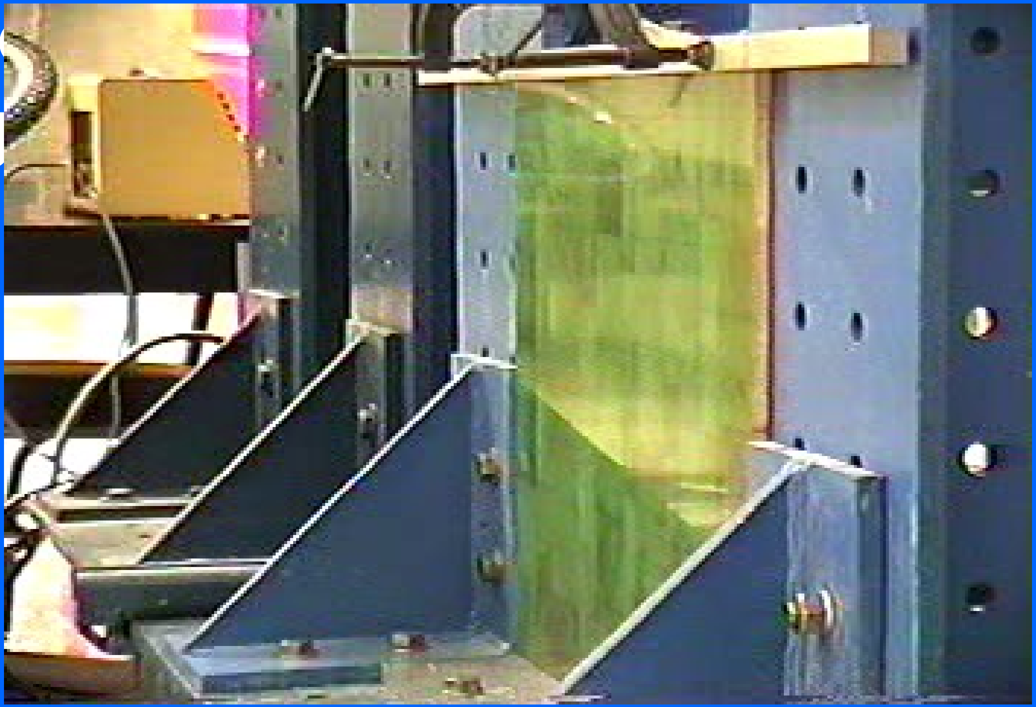






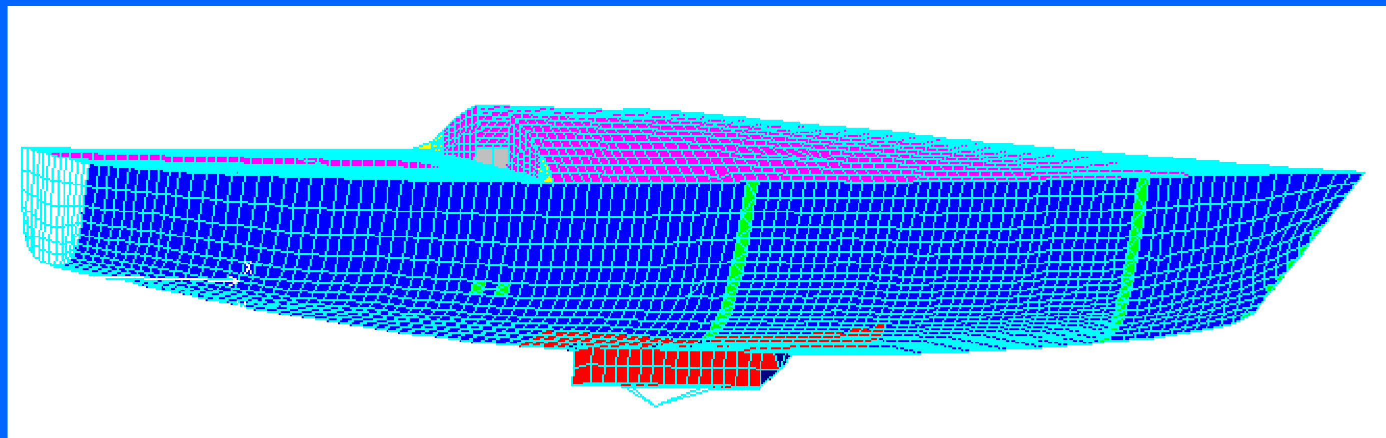
Impact Testing

- **The newest boat had the lowest stiffness.**
- **Did the collisi microcracking**



Yes, there was significant microcracking!

Global FEA

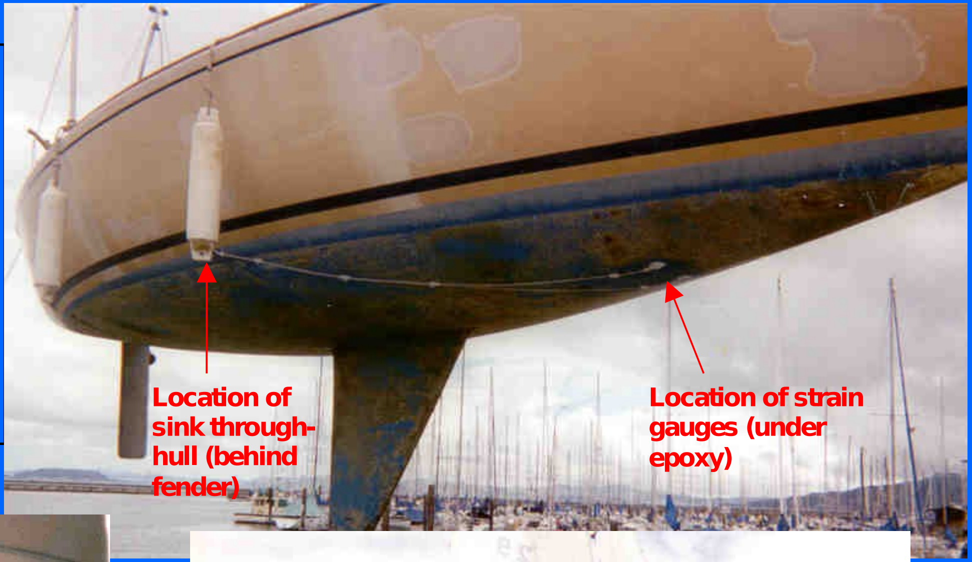


- Created from plans and boat checks
- Accurately models vessel
  - 8424 quad shell elements
  - 7940 nodes
  - 46728 DOF
- Load balance with accelerations

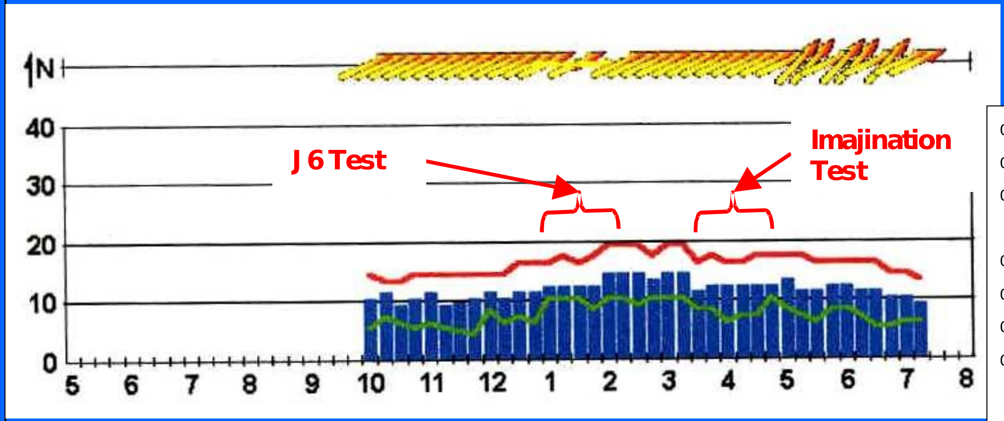
On-The-Water Testing- Set Up

Instrument Locations for Boat Tests

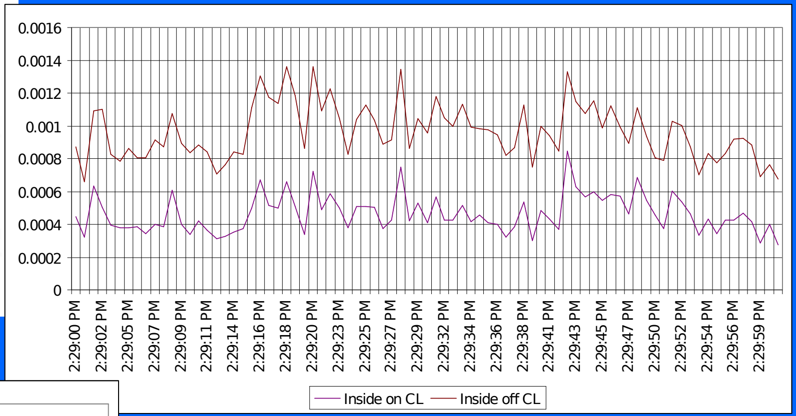
Instrument	*Location*
Strain Gage #1	Portside shroud chainplate
Strain Gage #2	Forestay chainplate
Strain Gage #3	Inside hull on centerline
Strain Gage #4	Inside hull off centerline
Strain Gage #5	Outside hull on centerline
Strain Gage #6	Outside hull off centerline
Accelerometer	Bulkhead aft of strain gages



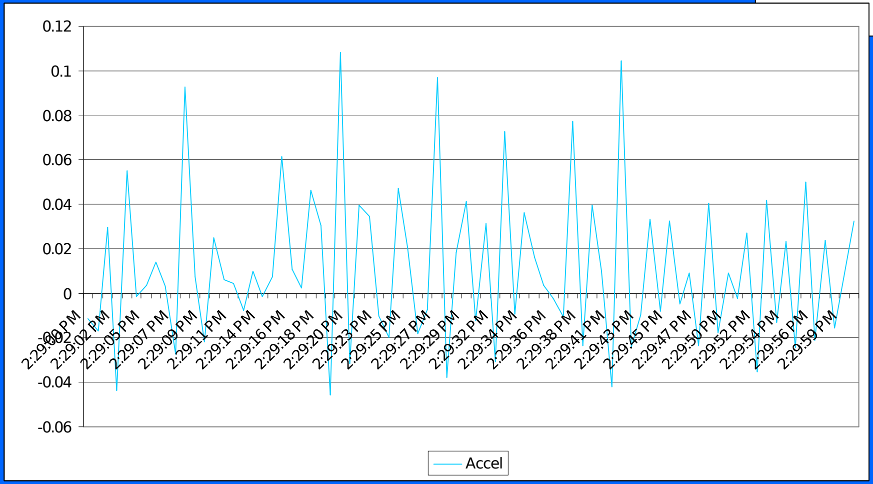
Data Records



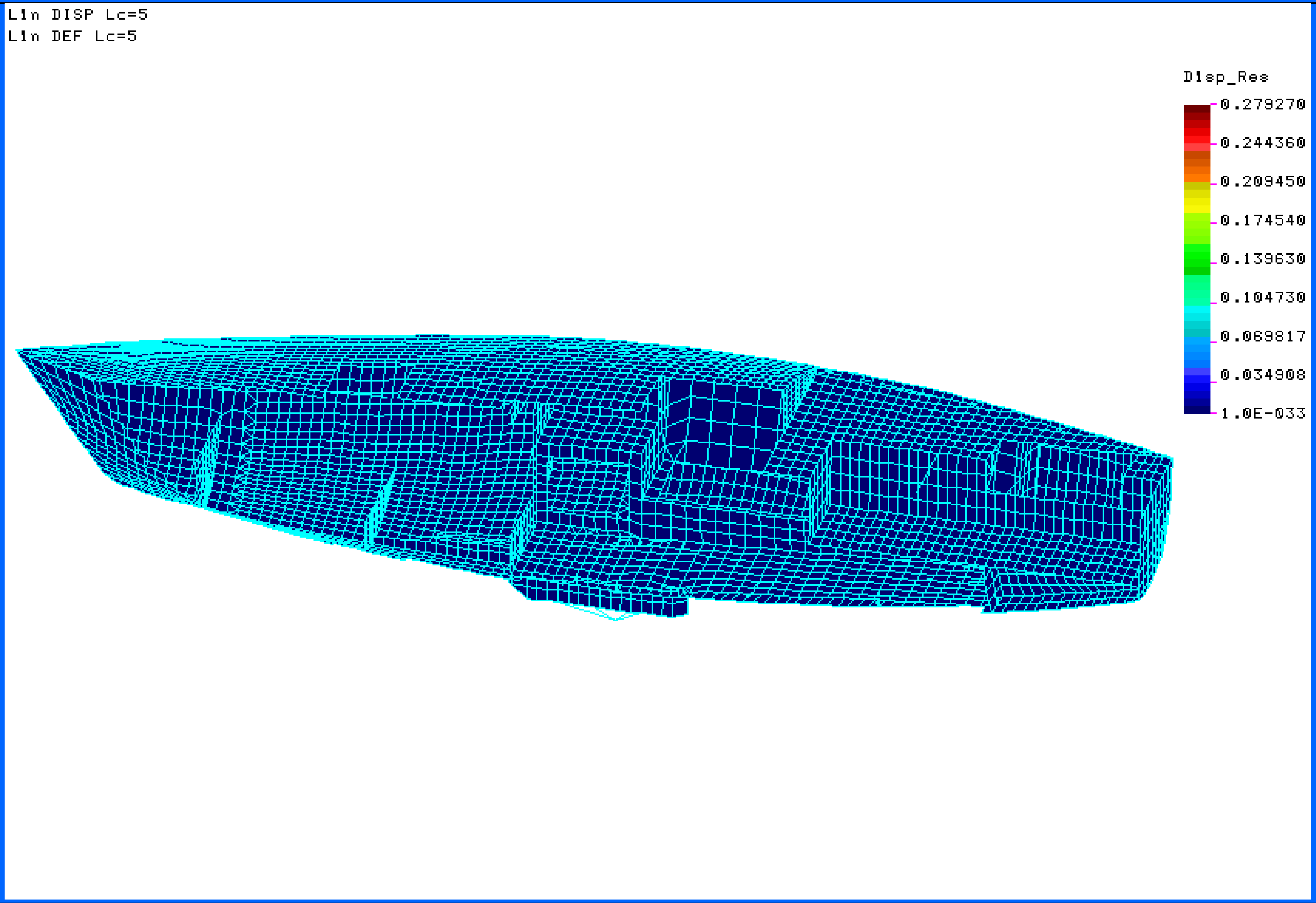
Wind



Strains



Accelerations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